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TECHNIQUES FOR METRIC PHOTOGRAPHY

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TECHNIQUES FOR METRIC PHOTOGRAPHY

J. G. Waugh[1], A. T. Ellis[2], and S. B. Mellsen[3]

Abstract

Three techniques for metric photography are described. In the first, missile position-time data are obtained from measurement of photographs of the virtual image produced in a precision-ground sphere by a timed stroboscopic point-source lamp. In the second, a rotating circular film disk is covered with sector-shaped exposures using a timed stroboscopic lamp. In the third, the previously described techniques are combined to obtain data simultaneously.

Introduction

In hydrodynamic studies at the California Institute of Technology, Pasadena, California, on the motion of 1-inch-diameter precision-ground, highly polished steel spheres over distances of a few inches, it was necessary to measure accurately by photography small displacements of the spheres over successive intervals of time. In addition, it was necessary to obtain synchronous photographic data on associated hydrodynamic phenomena such as water-surface deformation which would also be suitable for measurement, although not to the degree of accuracy required for sphere-position measurement.

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Highlight Camera

In sphere-position measurement, the customary technique of placing marks on a missile could not be employed because the studies precluded modifying the sphere surface in any way and any rotation of the sphere would have introduced error into the data. Although measurement of position from sphere photographs was attempted by setting the cross hairs of a measuring microscope or comparator on the curved edge of the sphere image, the required degree of precision could not be attained.

The feasibility of using photographs of the virtual image or "highlight" produced in a sphere by a stroboscopic point-light source to obtain accurate sphere position-time measurements had been demonstrated in tests at the U. S. Naval Ordnance Test Station, Pasadena, California (Ref. 1). It was felt that with further refinement of the technique, the required degree of accuracy could be attained. The small circular highlight photographs would permit precise centering of the cross hairs of a measuring microscope, and hence, measurement of highlight (i.e., sphere) positions. When the tests were conducted in a darkened room, the intensity of the highlight would permit many exposures on a stationary film, thereby increasing the convenience of obtaining data and the accuracy resulting from recording data on the same film. Moreover, since the spheres were precision-ground, their rotation would not sensibly affect the position of the highlight. By suitably positioning the light and camera with respect to the trajectory of the sphere, as described later, the projections of the highlights on the object plane could be made to coincide with the positions of the sphere center, except for a slight lateral offset perpendicular to the motion

of the sphere and hence not involved in the calculation of the sphere velocity and acceleration.

A simple application of the highlight technique for use in air is illustrated in Figure 1. It consists of a stroboscopic point-light source, L, and a camera so positioned that the trajectory of the sphere center, C, lies in the object plane of the camera, and points along the trajectory would be equidistant from the light source and camera lens node, N. For a ray of light from the point-light source to be reflected from the sphere (assumed to be moving vertically) into the camera lens, it is necessary that the incident and reflected rays lie in the plane defined by LCN. Then the point of reflection, S, will lie in LCN as will the virtual image (highlight), L_1, which is situated midway between the surface and center of the sphere. The projection of L_1 on the object plane is L_2 and will be at the same height as C, although displaced slightly to one side of it. Consequently, insofar as vertical measurements are concerned, the highlight represents accurately the position of the center of the sphere and may be used for distance, velocity and acceleration measurements. The highlight may also be used for fairly accurate measurements of the lateral deviation of the sphere in the object plane, if these deviations are small, because the relation of the projection of the highlight to the center of the sphere would not be appreciably altered. Since precision-ground spheres up to a diameter of 1-5/16 inch with a sphericity tolerance of 0.000025 inch are easily obtainable, the position of the highlight is practically unaffected by sphere rotation.

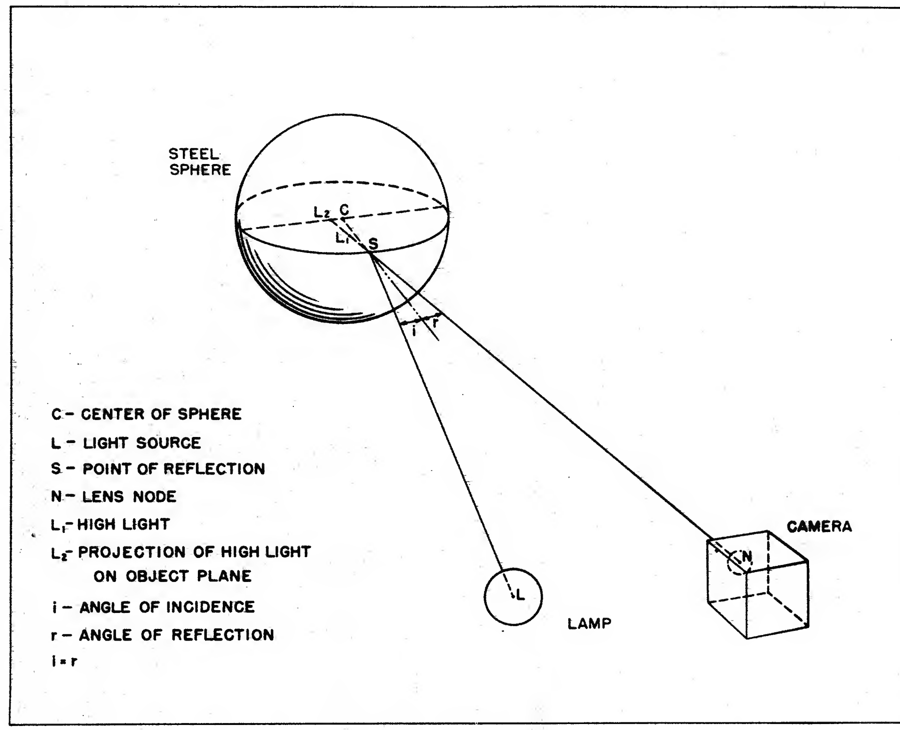


Figure 1 - Diagram of Optical Setup for Highlight Method of Sphere-Position Measurement in Air.

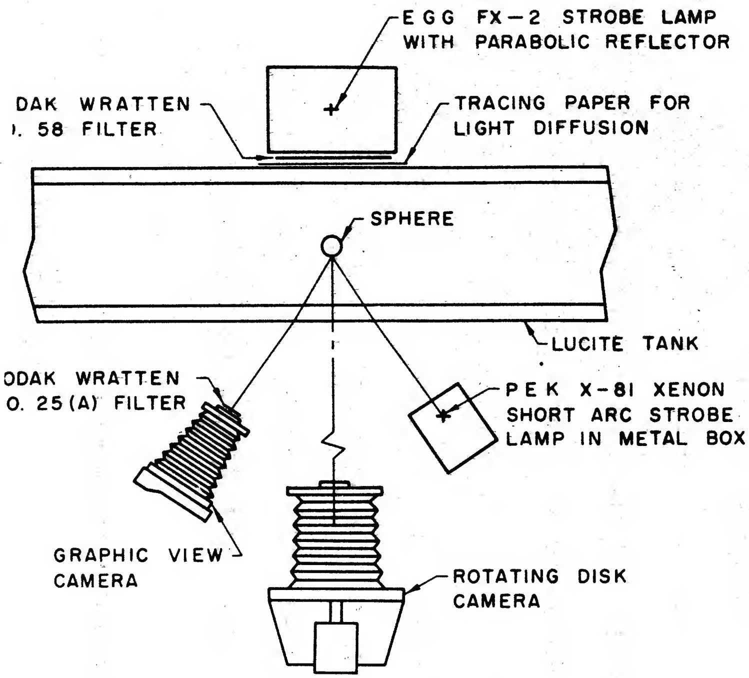


Figure 2 - Optical Setup for Rotating-Disk Camera and Highlight Method of Sphere-Position Measurement in Water.

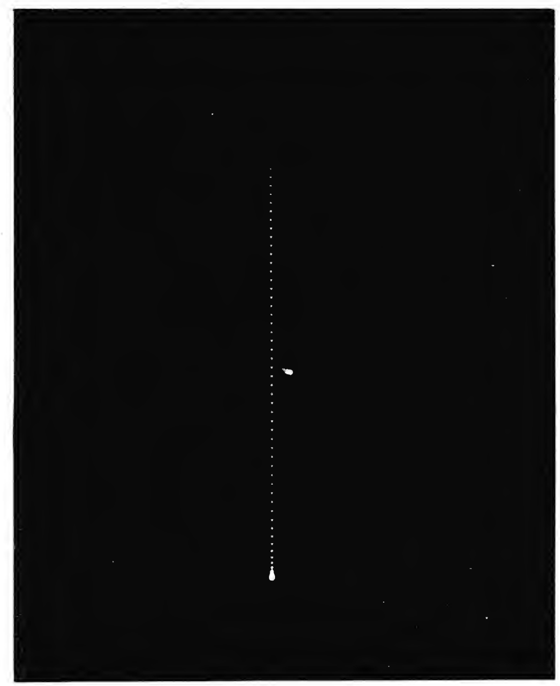


Figure 3 - Highlight Film of 1-Inch-Diameter Sphere Moving Vertically Upward in Water. Time between successive exposures 1/1000 second.

A similar simple application of the highlight technique in which the sphere is immersed in water can also be used. Here, in addition to the above constraints, it is necessary that the trajectory of the sphere be parallel to the plane surface of the water tank window and that the point-light source and lens node be equidistant from the window. This setup, together with a rotating-disk camera, is illustrated in Figure 2. For studies conducted at the California Institute of Technology, a PEK X-81 Xenon Short Arc lamp of about one-microsecond flash duration, made by PEK Labs Inc., Sunnyvale, California, has been used as the point-light source. A Graphic View II camera fitted with a Kodak Commercial Ektar f:6.3, 8-1/2 inch focal length lens and a Polaroid Land camera back is used with Polaroid 3000 Speed/Type 47 film to obtain highlight data.

A Kodak Wratten No. 25(A) red gelatin film filter cemented between circles of optical glass is mounted in front of the camera lens. This filter reduces the light wavelength range (and hence light dispersion due to tank-wall prismatic effects), resulting in sharper highlight images. The filter is also used in a technique to obtain simultaneous highlight and rotating-disk camera data. This technique will be described later.

Both the camera lens node and lamp are 8 inches from the Lucite tank wall which is 2 inches thick. The 1-inch-diameter sphere is 9 inches from the tank wall, and the magnification factor for highlight photography is about 1.1. When the sphere is immersed in water, the camera lens stop is f:32 and in the absence of water it lies between f:32 and f:45.

In order to focus the camera, a sphere of the size to be studied is

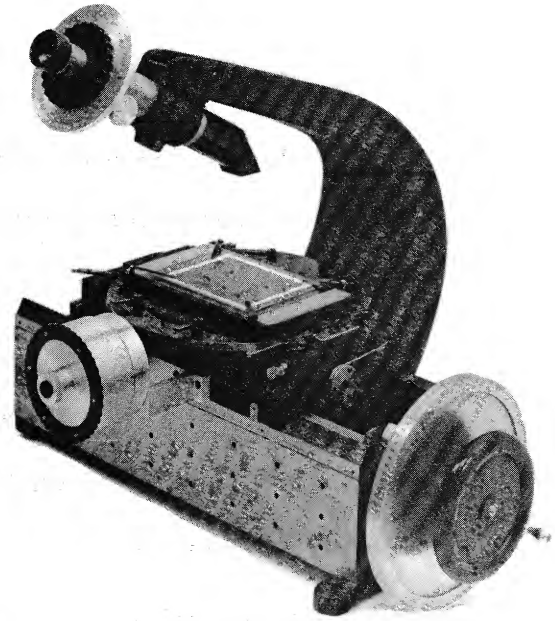
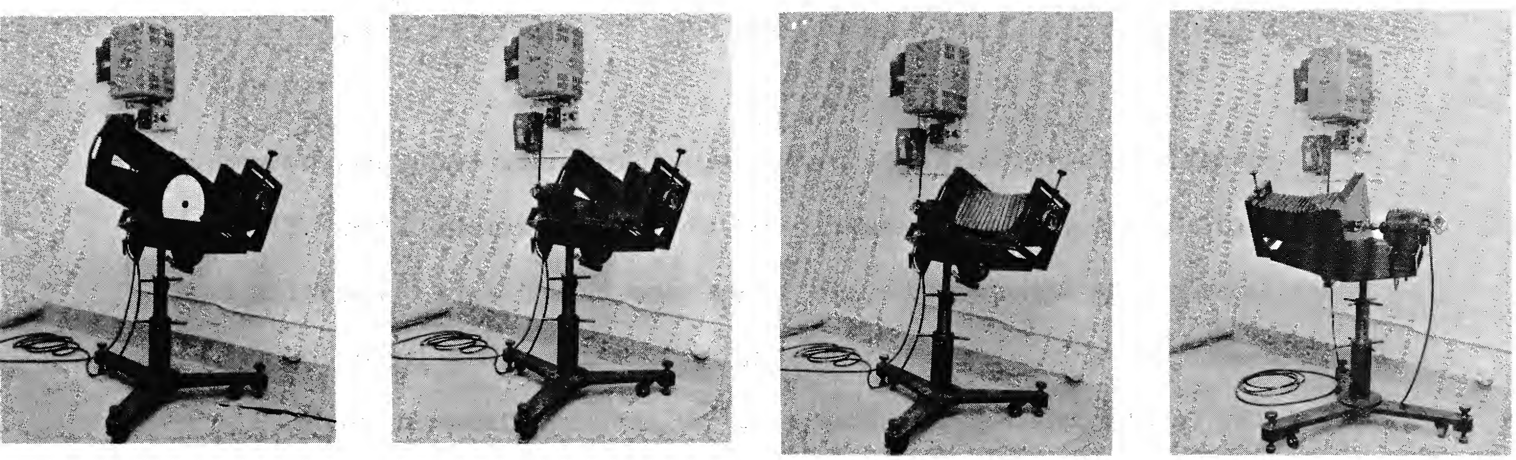


Figure 4

- Measuring Microscope Used in Highlight and Rotating-Disk Film Data Reduction. Lamps (not shown) provide direct and transmitted light for photographic measurement.



(a) (b) (c) (d)

Figure 5 - Rotating-Disk Camera. (a) Completely open. (b) Open with triangular slot in place. (c) Completely closed. (d) Rear view of camera. Motor speed-control unit mounted on wall.

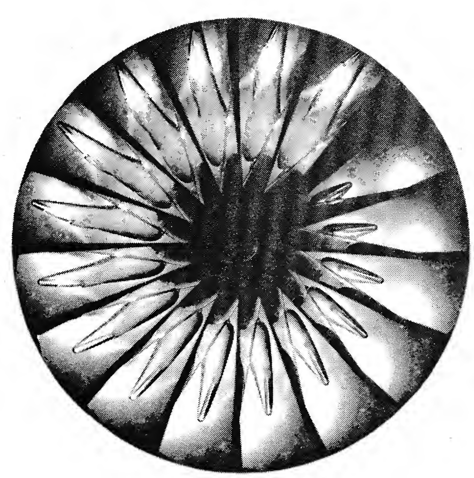


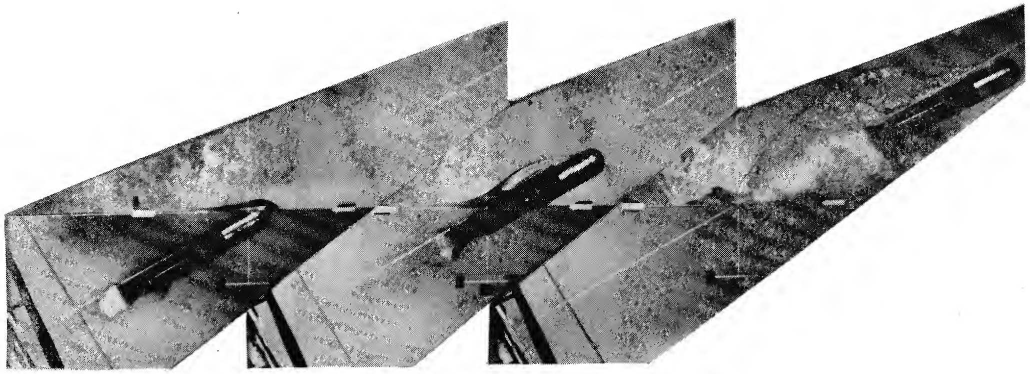
Figure 6

- Rotating-Disk Camera Film Showing Oblique Water Entry of 2-Inch-Diameter Hemisphere-Head Missile.

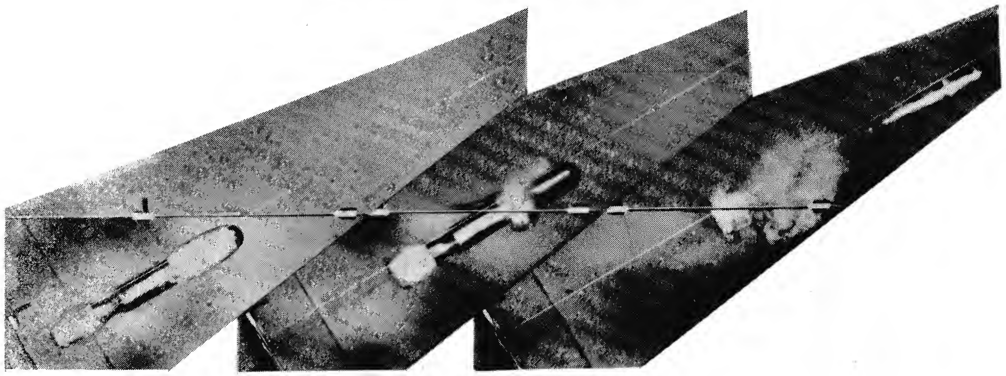
positioned so that its center is in the object plane at some suitable point in the trajectory. A zirconium concentrated arc lamp (Sylvania C2/DC/S lamp) is placed just in front of and in line with the stroboscopic lamp and the sphere. The room is then darkened and the camera, with lens fully open, is focused on the highlight produced in the sphere by the zirconium lamp, after which the lamp and sphere are removed. A 2- or 3-power hand magnifier is helpful in obtaining a good focus. The range and number of sphere positions to be observed over the exposure sequence is adjusted by setting the frequency and gating the number of flashes. A time-delay generator, adjustable to one microsecond, triggers the flash sequence at the appropriate instant.

To obtain data, the room is darkened, the camera shutter opened, the equipment and stroboscopic lamp actuated after which the shutter is closed. Calibration of the highlight system consists of photographing, without change in focus adjustment, a scale in the object plane placed along the line of the trajectory of the sphere center.

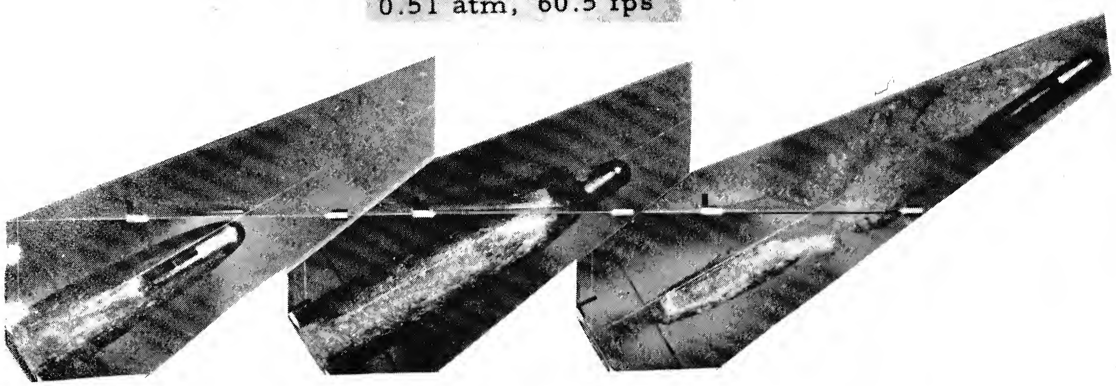
Figure 3 shows a typical highlight film with 55 highlight images as indicated by an electronic counter. These images are clear and sharp, except for those obtained during the initial slow motion of the sphere starting from rest. As many as 100 exposures have been taken without noticeable loss of contrast with the background. The images are round and our experience indicates that the cross hairs of a measuring microscope may be centered on them with a precision of ±5 microns for good highlights and ±2 microns for very good highlights. The position of the highlight images is measured by means of a measuring microscope (Figure 4) constructed by David W. Mann, Precision Instruments,



1.00 atm, 56.0 fps

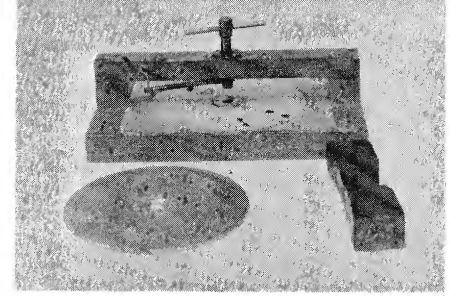


0.51 atm, 60.5 fps

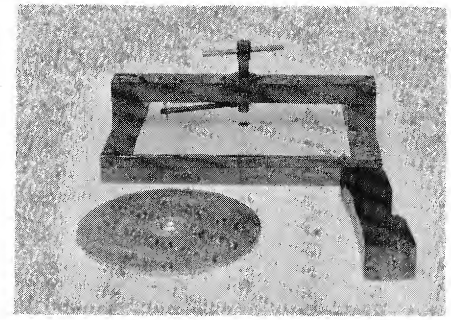


0.10 atm, 58.7 fps

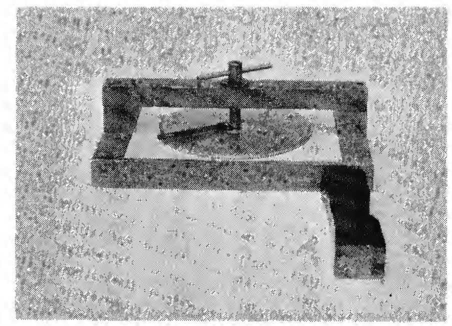
Figure 7 - Water-Exit Behavior of 2-Inch-Diameter Hemisphere-Head Missile Launched at 30-Degree Trajectory Angle for Varied Conditions of Cavitation. Air pressure over the water surface and water-exit velocity are given for each launching. (Taken from Ref. 2).



(a)



(b)



(c)

Figure 8 - Disk Film Cutter. (a) Disassembled. (b) Cardboard backing-sheet in place. (c) Assembled with film in place for cutting. Right foreground: wooden block used with cutter.

Lincoln, Massachusetts. This instrument has a measurement capability of 200 millimeters in the horizontal (abscissa) and 30 millimeters in the vertical (ordinate) directions. The readout is one micron. The stage and cross hairs may be rotated and both are provided with circular angular scales with verniers so that angles may be read to one minute.

A disadvantage of the highlight technique is its limitation to precision-ground light-reflecting spheres. The technique can, however, be extended to missiles on which it is feasible to mount such spheres. A stationary sphere or spheres in the object plane could be used to provide fiducial highlight images for measurement of missile positions. The technique could be extended to obtain highlight images in a plane normal to the object plane. These could be used to determine whether or not the sphere deviated from the object plane and to obtain additional data.

Rotating-Disk Camera

A special rotating-disk camera (Figure 5), designed and fabricated at the U. S. Naval Ordnance Test Station, Pasadena, California, was found suitable for metric photography of other associated phenomena such as water-surface deformation. This camera is briefly described in Reference 2. Essentially it consists of a 5 x 7 view camera (without back) mounted on a housing containing a rotating disk with a circularly cut photographic film 11 inches in diameter clamped to the surface. An adjustable triangular slot limits the photographic exposure to a sector for each flash of the stroboscopic lamps. The disk is rotated at any speed up to 3400 rpm ± 0.5 percent of set speed with a General Electric Thymotrol controlled speed motor. The speeds are set with

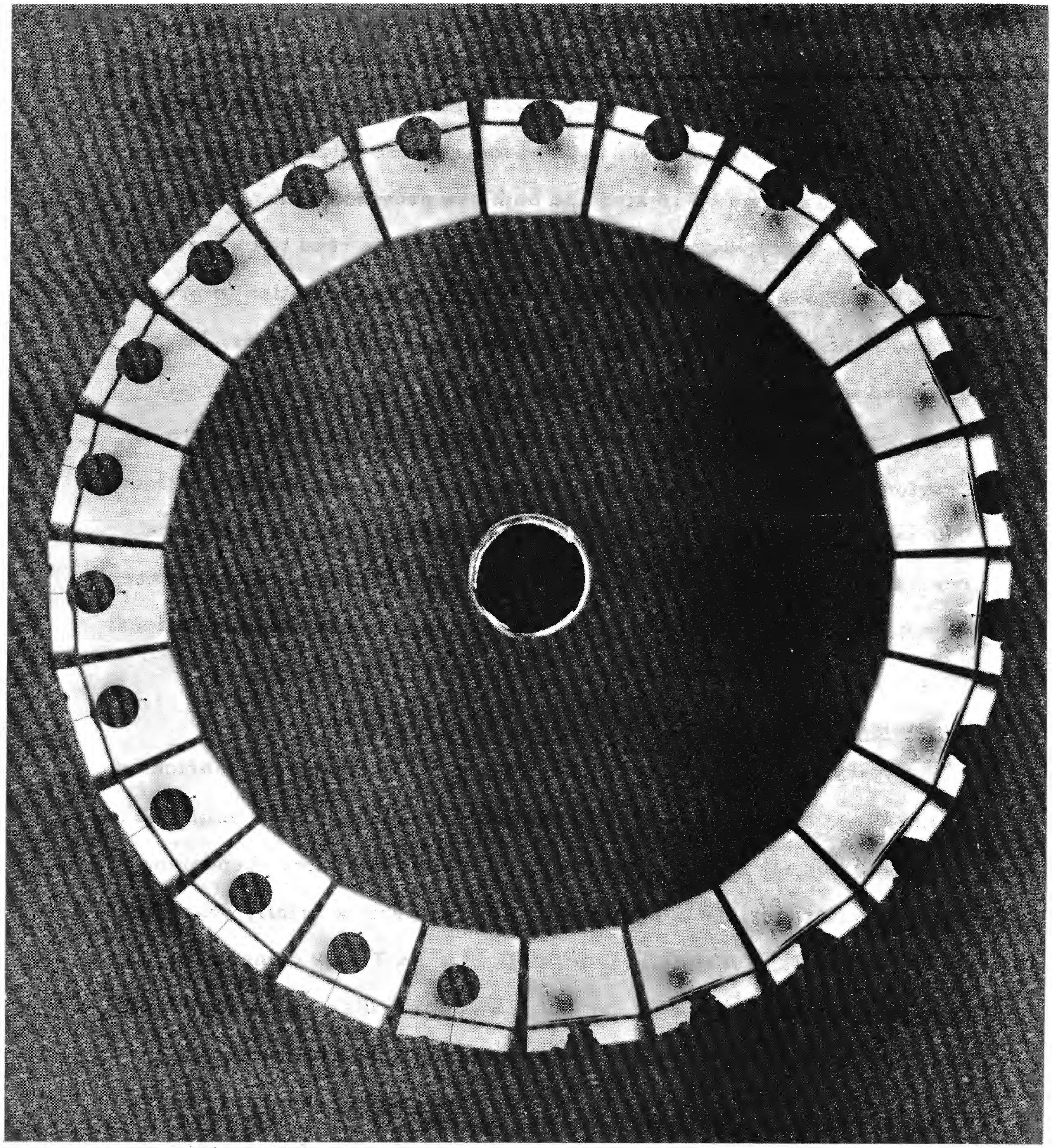


Figure 9 - Rotating-Disk Camera Film Showing Water Exit of 1-Inch-Diameter Sphere. Time between successive exposures 1/1000 second.

a revolution counter and a stop watch for low speeds or with a stroboscope for high speeds. Before launchings are made, the field of photographic coverage, the number of exposures, and the time interval between exposures are determined. From this the camera-slot opening and the disk speed are derived and the electronic apparatus set to give the preassigned number of lamp flashes (exposures) at the desired frequency. By properly gating the number of flashes, the complete disk may be covered with exposures. The range of missile positions over the exposure sequence can be set with a time-delay generator, adjustable to one microsecond, that triggers the flash lamps at the appropriate instant.

The camera is mounted on a steel stand provided with casters. After the camera is positioned, it is fixed and leveled by screws in the base which contact the floor and raise the casters from it. The height of the camera lens from the floor is adjustable from 3 to 5-1/2 feet by means of telescoping threaded tubes in the central column of the stand.

The film for the camera is cut in an 11-inch diameter circular disk with a 3/4-inch diameter hole in the center. In loading the camera, the room is darkened and the camera completely opened as in Figure 5(a). A spring-loaded retractable pin in the back of the camera housing is pushed forward and the disk slowly rotated until the pin engages a blind hole in the back of the disk, thereby locking it so it cannot rotate. The pin is locked so that it cannot retract, a circular film is then seated over a 3/4-inch diameter threaded stud at the center of the disk, and a 2-inch diameter circular knurled nut is screwed down snugly by hand on the stud so that the film is held at its center. A flanged rim is locked

on the disk and holds the film at the circumference. The pin is then released, freeing the disk, and the camera closed, following the reverse sequence shown in Figure 5(a) - (c).

To unload the camera it is opened, the disk locked in position, and the nut, the rim, and lastly, the film, removed. For positioning and focusing and sector adjustment, a piece of white cardboard sheet is clamped to the ring in place of a film, the sector-opening assembly is slid into place, and the operation performed with the camera bellows retracted, as in Figure 5(b). A hand lens for viewing the image formed on the white cardboard is helpful in focusing. To obtain data, the camera motor is brought up to speed, the room darkened, the shutter opened, the equipment and lights actuated, and the shutter closed.

A typical rotating-disk camera film is shown in Figure 6. A composite photograph, including selected frames from a missile water-exit launching, is shown in Figure 7 (taken from Reference 2). The advantages of rotating-disk cameras over strip cameras, in these studies where few exposures are required, is that there is no film waste in starting and stopping the camera and the larger frames permit closer detail and greater metric accuracy. A Bausch and Lomb Tessar f:4.5, 11-7/8-inch focal-length lens is currently being used in the camera, but any lens suitable for a 5 x 7-inch view camera can be used.

The circular-disk film used is cut from sheets of 11 x 14-inch film available from Eastman Kodak Company. The film cutter, adapted for use in total darkness, is shown in Figure 8. It is a heavy wooden frame holding a mandrel or quill assembly consisting of a 3/4-inch diameter

steel shaft with a radius cutter mounted in a close-fitting bronze sleeve. The lower end of the mandrel is machined flat with a sharp edge and is aligned with a circular hole of the same diameter in a steel plate mounted flush in the base of the frame. The function of the mandrel is to punch a circular hole in the film and cut a circular disk centered about the hole. The base of the film cutter has a rectangular depression to index the position of the sheet of film for cutting.

To operate the film cutter, a wooden block is placed under the mandrel handle to hold the assembly up from the base. An 11 x 14-inch sheet of cardboard is placed in the rectangular depression of the film cutter and the mandrel is lowered to the cardboard and given a sharp blow with the block to cut out a center hole. The purpose of the cardboard is to provide soft backing material for the radius cutter knife. Sheets of cardboard cut to size are included in the film boxes. One sheet usually suffices for cutting a dozen or more sheets of film.

To cut film, the mandrel assembly is held clear of the base, and a sheet of film positioned by touch in the cutter. A circular metal plate is placed over the film to hold it flat while it is being cut and the mandrel shaft lowered through a hole in the center of the plate. This hole is beveled so that the shaft and hole can be easily aligned in the dark. The shaft is then driven through the film and the mandrel handle turned with a slight downward pressure through one revolution while the metal plate is held against the film to prevent buckling. The mandrel assembly is then raised, the metal plate removed, and the cut film placed in a storage box for subsequent use.

Combined Highlight and Rotating-Disk Camera Techniques

A combination of the highlight and rotating-disk camera techniques has been used to obtain synchronous photographs of the sphere position and perturbation of the water surface as the sphere moved vertically toward it. The setup is shown in Figure 2. The rotating-disk camera was positioned so that its lens axis was normal to the water-tank window and lay in the plane of the undisturbed water surface. An Edgerton, Germeshausen, and Grier FX-2 stroboscopic lamp of about one-microsecond flash duration with opalescent paper was used to provide diffused background illumination for silhouette photographs of the water surface. A Kodak Wratten No. 58 green filter in front of the FX-2 lamp and the Kodak Wratten No. 25(A) red filter in front of the highlight camera lens prevented fogging of the highlight film by light from the FX-2 lamp. The X-81 lamp light did not adversely affect rotating-disk camera photography and no additional light filtering was needed. Both stroboscopic lamps were pulsed simultaneously to obtain synchronous data.

A rotating-disk camera series of photographs of the water surface using Kodak Royal Pan film is shown in Figure 9. The image of the X-81 lamp shows as a highlight in the sphere. Twenty-three photographs were taken with a time interval of one millisecond between successive frames. The corresponding highlight film is similar to that in Figure 3. While this particular setup illustrates the combined use of both techniques, other variations can be used, such as, for example, front illumination for rotating-disk camera photography.

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